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Environmental Impact and Cost Benefit Analysis of Biological Control Application

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ABSTRACT

The implications and interactions of the application of biological control agents in the environment, as well as the risks included by the introduction of exotic natural enemies are briefly reviewed. Description of the role of resistance or quality of the host plant to insect pests, and their interaction with biocontrol agents is provided. A need to increase applications or find new alternatives and environmental impact towards non target insects, and the real cost of its use against the benefits is discussed.

INTRODUCTION

We propose to show the implications, and interactions of the biological control application in the environment, the risks which could include the introduction of exotic enemies, role of the resistance or quality of the host plant, and the necessity of increase applications or finding new alternatives and environmental impact towards non target insects, and the real cost of its use against the benefits it provides.

The United Nations have been adopting the multidimensional development approach and the capability approach since the 90's, both proposed by the economist and Nobel Price Amartya Sen in the framework of his analysis of human development concept. In this framework, health is a constitutive dimension of human development and environmental health can seen as a social condition historically linked to society's industrialization and urbanization (Marsili, 2009).

Agriculture is one of the means to achieve capabilities for the wellbeing and quality of life. This human activity faces limitations caused by the outbreaks of severe infestations of pests and diseases. The use of synthetic pesticides has been the most common method to reduce the pest and disease populations; however, the abuse of use of these chemicals caused impressive damage in the agroecosystem integrants. In response to their negative impacts, social, economic and ecological concerns have demanded alternative methods to reduce the pests and diseases.

The Integrated Pest Management (IPM) is a pest management strategy that focuses on long-term prevention or suppression of pest problems through a combination of practices such as regular pest population monitoring, site or pest inspections, an evaluation of the need for pest control, occupant education, and structural, mechanical, cultural, and biological controls (BC). Under the umbrella of the IPM, BC is the introduction of native enemies of exotic pests into new areas in an attempt to reduce the population sizes of those pests (Hufbauer, 2002).

Usually, the BC is considered an alternative and efficient strategy to reduce pest populations, but the impact of alien species on native organisms is a cause for concern worldwide, with biological invasions commonplace today (Kaufman and Wright, 2009).

Loope and Howarth (2003) emphasized that the proliferation of transportation continues to break down biogeographical boundaries with profound consequences, and an evergrowing volume of transported goods, increasing efficiency and speed, advancing technologies, and trade agreements are key of the phenomenon (Bright, 1999); this is accelerating the rate of biological invasions to a degree without precedent (Stanaway, 2001).

The practice of BC for pest management has been commonly recognized as an effective suppression method for invasive species, and its use was encouraged to reduce dependence on insecticides for the management of invasive insect pests (Kaufman and Wright, 2009); however, BC sometimes also affects the native BC agents.

Based on this background a question comes: is biological control a feasible alternative for a healthy environment at a low cost? Usually, when we talk about a health environment, we expect an environment free of pesticides; however a health environment also implicates the absence of risks for the integrants of the agroecosystems. The native BC agents sometimes are affected by exotic BC agents, and the "healthy

environment" is placed in a weak position; one of the most harasser phenomena is the extinction of BC species, and it has a high cost for biodiversity.

The benefits of biological control are those that can provide fairly permanent regulation of devastating agricultural and environmental pests that may be difficult or impossible to manage with more traditional chemical means. However, there are obvious risks. Biological control agents may negatively affect native species directly or indirectly. Historically biological control introductions were not regulated the way they are today, and some horrible mistakes were made in the name of biological control (*e.g.* cane toads in Australia). Even relatively specialized herbivorous insects released for the biological control of invasive weeds can pose risk to related native plants (Hufbauer, 2009).

In order to address a response it is necessary to particularize the cases, and we show some of them because the information available has a broad spectrum.

COMPETITION BETWEEN NATIVE AND INTRODUCED PARASITOIDS OR PREDATORS

There has been much debate about the potential impact of biological control application on nontarget species; many examples seen to show that nontarget species suffer a negative impact from biological control agents, although the quality of evidence varies from anecdotal to relatively quantitative (Stiling and Simberloff, 2000), and the paucity of detailed studies makes it difficult to assess the frequency and severity of nontarget effects (Lynch and Thomas, 2000; Lynch *et al.*, 2002).

Relatively little attention has been given to indirect nontarget effects in which a nontarget species is affected by the biological control agent without suffering direct attack (Huffaker and Kennett, 1966), those effects that do not involve control agents directly attacking nontarget species (Schellhorn *et al.*, 2002).

Schellhorn *et al.* (2002) reported on a study combining experiments, theory and historical information to investigate the decline of a native parasitoid from an agricultural system possibly caused by indirect effects from an exotic parasitoid introduced as a biological control agent. The native parasitoid *Praon pequodorum* Viereck (Braconidae: Hymenoptera), in alfalfa cropping systems suffered a decline due an exotic introduced competitor, *Aphidius ervi* Haliday (Braconidae: Hymenoptera) used against the pea aphids.

At the population level, *P. pequodorum* caused higher parasitism than *A. ervi* when the overall level of parasitism was higher, due a *P. pequodorum* superior with-in host competitive ability. A negative correlation between *A. ervi* and *P. pequodorum* parasitism per plant, suggested strong competition by larvae within host or behavioral avoidance of previously parasitized host by *P. pequodorum.*

Comparing the searching behavior, Schellhorn *et al.*, (2002) considered that *A. ervi* is a superior among-host competitor, searching longer on a plant after an aphid is encountered, moving more rapidly within plants, and attacking and parasitizing more aphids per unit time than *P. pequodorum.* They concluded that indirect nontarget effects of biological control may depend on agricultural practices and the consequent disturbance regime of human-dominant systems.

According to the last statement, With *et al.*, (2002) sustain that the habitat loss and fragmentation are becoming a serious impediment to the biological control of insect pests, particularly within managed systems such as agroecosystems. The habitat fragments support a less diverse community of natural enemies, resulting in lower predation or parasitism rates on pest populations (Roland and Taylor, 1997).

Thus, the potential of predators such as coccinelids to control pest populations in fragmented landscapes may ultimately reflect the extent to which thresholds in landscape structure interfere with aggregative response of predators. With *et al.*, (2002) emphasized that habitat fragmentation may adversely affect the ability of natural enemies to control pest outbreaks in agricultural landscapes by interfering with their search behavior and ability to aggregate in response to prey.

In other hand, Lynch *et al.*, (2002) discussed that even relatively little-preferred nontarget hosts may be at risk of severe population reduction, and perhaps local extinction, from the introduction of a parasitoid biocontrol agent during transient periods just after agent introduction. Extinction of nontargets organisms caused by biological control agents in the past has been believed by several authors, and they sustain that the risk continues (Howarth, 1983; Strong, 1997; Kuris, 2003).

The biocontrol of insect pests may pose a risk to native insects if the biocontrol agent attacks nontarget species (Lynch *et al.*, 2002). However, Van Lenteren and Martin (1999) working with whiteflies are skeptical, critical of the quality of the evidence in general, and they believe extinction or serious population reduction is impossible given the precautions of modern-day biocontrol.

COMPETITION BETWEEN GENERALIST AND SPECIALIST PREDATORS

Biological control theory for predator-prey interactions has been based upon a model communities composed of three discrete trophic levels- plants, herbivores, and predators- in which biological control agents are top consumers and in which different species of predators interact only through competition for shared prey (Rosenheim *et al.*, 1999).

Increased attention has recently been directed to the role of generalist predators as regulators of insect herbivore populations in agroecosystems. Hassell (1978) based in the correspondence between the models and field and laboratory data, discusses the practical implications for biological pest control and suggests how such models may help to formulate a theoretical basis for biological control practices. The dynamics of specialist natural enemies are tightly linked to those of a target pest. This concept has been highlighted by the theory and practice of the biological control.

Hassell (1978) considers in detail several crucial components of predator-prey models: the prey's rate of increase as a function of density, non-random search, mutual interference, and the predator's rate of increase as a function of predator survival and fecundity.

Sheehan (1986) stated the effects of agroecosystem diversification on searching behavior and success of arthropod natural enemies are poorly understood. Crop diversification may increase generalist enemy effectiveness by increasing alternate food or prey availability, as predicted by the enemies hypothesis. But diversification may also reduce enemy searching efficiency and destabilize predator/prey interactions.

Additionally, specialist enemies, often important in biological control programs, may be particularly sensitive to vegetation texture. Pest control by specialist enemies may be more effective in less diverse agroecosystems if concentration of host plants increases attraction or retention of these enemies.

The dynamics of discrete, insect host-parasitoid interactions, having both populations coupled and synchronized with each other, it is implicitly assumed that the parasitoids are effectively specialists on that one host species. However, many natural enemies of insects are polyphagous to some degree and will have rather different dynamical relationships with their prey; this is the case for many parasitoids, staphylinid and carabid beetles, birds and small mammals. A broad diet will tend to buffer the populations of such generalists from fluctuations in abundance of any one of their prey, and give dynamics

that are largely uncoupled from that prey (Southwood and Comins, 1976).

The relationships to population density of predations, intraspecific competition and female fertility are the major components in the population dynamics of many species. The way in which these relationships interact, and the resulting effect on the population is conveniently illustrated using a population growth curve, comparing their densities in successive generations (Southwood and Comins, 1976). Most insect populations are attacked by several natural enemies, some polyphagous and other more-or-less monophagous.

Hassell and May (1986) obtained four conclusions related with the generalist and specialist natural enemies in insect predator-prey interactions: i) a specialist can invade and co-exist more easily if acting before the generalists in the life cycle of the prey. ii) A three-species stable system can readily exist where the prey-generalist interaction alone would be unstable or have no equilibrium at all. iii) In some cases the establishment of a specialist leads to higher prey populations than existed previously with only the generalist acting, iv) in some cases, a variety of alternative stable states are possible, either alternating between two-species and three-species states, or between different three-species states.

COMPETITION BETWEEN GENERALIST PREDATORS

Generalist predators have also recently been placed at the center of acrimonius debate over the environmental risks associated with classical biological control, the importation of exotic species of predators to control invasive, usually non-native species of herbivores. Generalist predators may pose substantially enhanced risks of non-target impacts on endemic faunas. The characteristics that make generalists attractive as pest control agents, and in particular their ability to support significant populations by consuming alternate prey, may increase their likehood of producing localized or region al extinctions (Holt and Lawton, 1994; Rosenheim *et al.*, 1999).

Hairston *et al.*, (1960) proposed the context of community-ecology for predator-prey interactions, and it has been adopted as a model for biological control. This context assumes three discrete trophic levels (predators, herbivores, and plants) in which biological control agents are top predators and different species of predators interact only through competition for shared prey. However, Rosenheim *et al.*, (1998) proposed an alternative model in which arthropod communities may comprise

more than three tropic levels; trophic levels may be indistinct; predators may consume not only herbivores but also other predators; then biological control agents may therefore be intermediate rather than top predators, and omnivory, cannibalism and intraguild predation are widespread (Rosenheim, 1998; Rosenheim *et al.*, 1995, 1999).

Rosenheim *et al.*, (1999) concluded that a model incorporating higher-order predators and a greater diversity of trophic interactions may prove to be a more fruitful starting point in our search for general rules of pattern and process in the regulation of herbivore populations.

COMPETITION BETWEEN OMNIVORES AND PREDATORS

Omnivores may be more likely to suppress prey populations than strict predators under some circumstances (Eubanks and Denno, 2000). In order to determine the effects of plant quality, and prey abundance on the intensity of interactions involving an omnivorous insect, its two herbivorous prey, and their shared host plant; they found that variation in plant quality, prey abundance, and presence of alternative prey altered the functional response of the omnivorous big-eyed bug, *Geocoris punctipe* Say (Heteroptera: Geocoridae).

Eubanks and Denno (2000) determined that the presence of high-quality parts , such as lima bean pods, reduced the number of prey corn earworm [*Helicoverpa zea* Boddie (Lepidoptera: Noctuidae)] eggs and pea aphids [*Acyrthosiphum pisum* Harris (Hemiptera: Aphididae)] consumed by the big-eyed bug. The pea ahid populations were larger when caged with big-eyed bugs on bean plants with pods than plants without pods. Pods had and indirect but positive effect on the survivorship of herbivorous insects that feed on lima beans. They concluded that plant quality, therefore, mediates the effect of this omnivore on prey suppression.

Other important aspect to consider in the interactions is the supplementation of food. Recently, Shakya *et al.*, (2009) tested the short-term effects of intraguild predation and food supplementation on interactions between two predators, the phytoseid mite *Neoseiulus cucumeris* Oudemans (Acarai: Phytoseiidae), and the anthcorid bug, *Orius laevigatus* Fieber (Hemiptera: Anthocoridae), and their shared prey *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), on strawberry plants. All three consumers feed on strawberry pollen, both mites and bugs prey on thrips, and the bug also feeds on the mites (intraguild predation). In structurally simple arenas strong intraguild predation on mites by the bugs was recorded. In whole plant which is a more complex setting, the intensity of intraguild predation differed

among the plant structures. Pollen supplementation reduced both intraguild predation on thrips in a structurally simple setting. However, in the whole-plant experiments, the intraguild predation was more intense on pollen-bearing than pollen-free flowers.

Shakya *et al.*, (2009) determined how spatial dynamics, generated when consumers track food sources differently in the habitat and possibly when herbivorous and intraguild prey alter their distribution to escape predation, let to site-specific configuration of interacting populations.

They tested short-term effects of intraguild predation and food supplementation on interactions between two predators, a phytoseiid mite, *N. cucumeris* and the anthocorid bug, *O. laevigatus,* and their shared prey, *F. occidentals*, on strawberry plants. The three specimens feed on strawberry pollen, both mites and bugs prey on thrips, and the bug also feeds on the mites. They concluded that the intensity of resulting trophic interactions was weakened by food supplementation and by increased complexity of the habitat.

INTERACTION OF OMNIVORES-HOST PLANT, AND NATURAL ENEMY

Grosman *et al.*, (2005) remarked that considerably less attention has been devoted to investigating how predators (including omnivores and parasitoids) adapt to new host plants of their phytophagous prey. The adaptation of herbivorous arthropods to novel host plants has been a focus of ecological research for many years, but not in their predators.

The hypothesis of the enemy-free space suggests that plants may be included in the host range of herbivores because of lower predation and parasitism rates on novel host plants. This phenomenon could be important if natural enemies do not follow their prey to the novel host plant, at least not immediately, thus allowing the herbivores to adapt to the novel host plant.

When a phytophagous prey has the opportunity to adapt itself to a new host plant, it may impact on the behavior of the predator or the parasitoid; the presence of certain allelochemicals or metabolites may affect the preference of the natural enemy, playing these new host plant metabolites in the prey a dissuasive role, because the phytophagous contain unpalatable or toxic compounds originating from their new host plant (Grossman *et al.*, 2005). Also, the plant quality affects the survival and diet choice of omnivores (Molina-Ochoa *et al.*, 1999; Coll and Guershon, 2002), and the omnivores may have to adapt to be able to feed on novel host plants as much as herbivores.

Molina-Ochoa *et al.*, (1999) studied a tritrophic interaction, host plant, phytophagous pest, and natural enemy. The interactions were studied on an antibiotic variety of maize, Zapalote Chico #2451 P(C3). This variety exhibits a series of allelochemicals that affects the biology of the fall armyworm, *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae). When the fall armyworm larvae fed on meridic diet supplemented with Zapalote chico silks, their life cycle and their respiratory rates are increased. Increasing in this way the opportunity for parasitization from entomopathogenic nematodes in Petri dish experiments. The entomopathogenic nematodes of the genera, *Steinernema* and *Heterorhabditis* use the carbon dioxide as chemical signal to localize their hosts in soil and cryptic habitats. They found that the use of resistant varieties of corn reduces the concentration required for mean lethal concentrations, using *S. riobrave,* and *S. carpocapsae* all strains.

CONSIDERATIONS

We would like to point out certain considerations instead to give a response to a cost-benefit analysis, avoiding a very simple response or value of the biological control of insect pests in terrestrial environments.

It is important to consider that biological control is not a simple cause-effect lineal phenomenon, it is a net of interactions between the actors of the agroecosystem, including the human being as main modificator.

The application of a biological control agent demands a series of studies in order to establish the possible side effects of its introduction on native fauna or natural enemy of the insect pest. An impressive risk of the introduction of exotic enemies is the extinction of natural enemies.

The host plant, its chemical constitution, and quality may affect the biology of the insect pest, and may also affect directly or indirectly the biology of the parasite, parasitoid, predator or pathogen in consideration.

A resistant plant may also spread metabolites in the soil or in the insect pest affecting the biology of the introduced enemy, sometimes in favor or unfavorably.

The changes in the floristic composition of an ecosystem certainly may affect the size of the insect pest population, diversity, and behavior of natural enemies.

A deep search of native enemies of an insect pest should be conducted in order to determine the possible candidate to be selected to reduce the

insect pest population, instead the introduction of an exotic one. The exotic should be selected just in case that the native is unable to reduce the pest population.

The diversity of natural enemies is a resource, and treasure of each country, and a heritage of the world.

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